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Cleaning of Flue Gases from Waste Combustors

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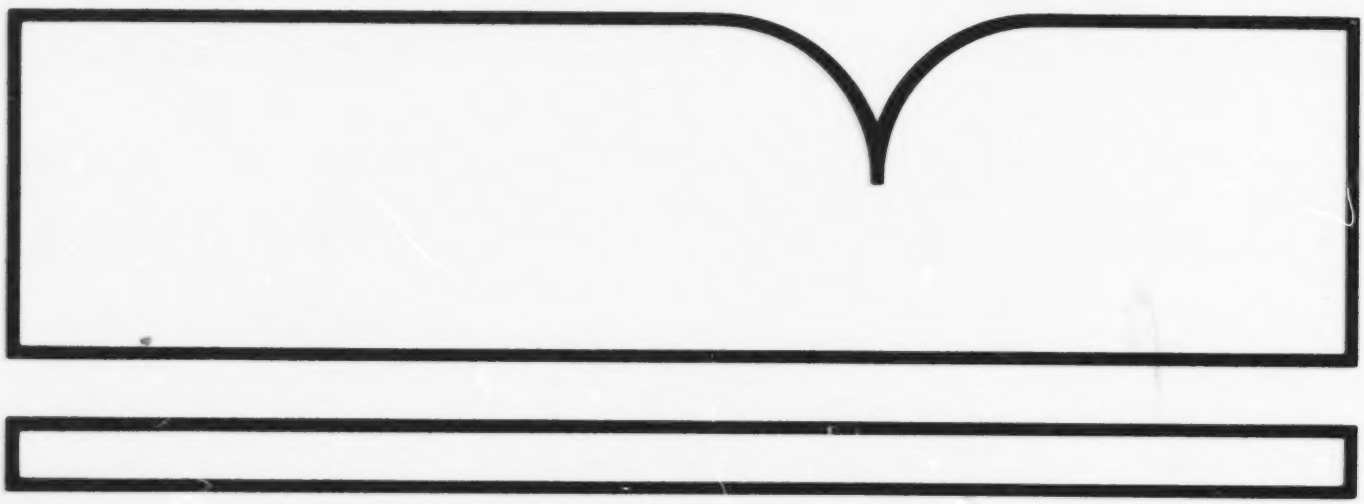

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16. ABSTRACT The paper addresses flue gas cleaning processes currently used commercially in waste combustion facilities. It also discusses the operating concepts of dry, semi-dry, and wet processes, and their effectiveness in controlling various pollutants. Air pollutants from the combustion of hazardous and municipal wastes which may require control include acid gases, organic compounds, heavy metals, and particulate matter. Dry, semi-dry, and wet processes are available to control these classes of gaseous pollutants. The process that represents the optimum solution depends on many factors, including type of waste/fuel, targeted pollutants and the desired level of control for each, location of combustion unit, and residue disposal restrictions. The combustion of hazardous and municipal wastes can effectively destroy targeted substances and reduce waste volume, thus extending the useful life of existing landfills. In addition, combustion may serve the beneficial conversion of waste to energy, such as for heating, cooling, or electrical energy applications. These benefits, however, are accompanied by the emission of air pollutants that require post-combustion controls in order to meet regulatory requirements.

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Pollution Particles	Pollution Control	13B
Flue Gases	Stationary Sources	21B
Cleaning	Municipal Wastes	13H
Wastes	Acid Gases	14G
Toxicity	Heavy Metals	06T
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CLEANING OF FLUE GASES FROM WASTE COMBUSTORS

by

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The combustion of hazardous and municipal wastes can effectively destroy targeted substances and reduce waste volume, thus extending the useful life of existing landfills. In addition, combustion may serve the beneficial conversion of waste to energy, such as for heating, cooling, or electrical energy applications. These benefits, however, are accompanied by the emission of air pollutants which require post-combustion controls in order to meet regulatory requirements.

Air pollutants resulting from the combustion of hazardous and municipal wastes which may require control include: acid gases, organic compounds, heavy metals, and particulate matter. Dry, semi-dry, and wet processes are available to control these classes of gaseous pollutants. The process which represents the optimum solution depends on numerous factors, including type of waste/fuel, targeted pollutants and the desired level of control for each, location of combustion unit, and residue disposal restrictions.

Flue gas cleaning processes currently used commercially in waste combustion facilities are addressed. The operating concepts of dry, semi-dry, and wet processes are discussed, and their effectiveness in controlling various pollutants is presented.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

Combustion is a viable option for destroying numerous hazardous and infectious wastes and for reducing the volume of non-recyclable municipal waste. In addition to conserving increasingly scarce landfill capacity in the U.S., the combustion of these wastes may serve the beneficial conversion of waste to energy for heating, cooling, or electrical energy applications. The benefits of burning these wastes, however, are accompanied by undesired by-products such as air pollution and residues with concentrated trace toxic organic and heavy metal compounds.

While the targeted hazardous wastes can be almost completely destroyed by combustion (99.99%), trace quantities of incompletely burned products, especially dioxins and furans, may be present in the combustion or flue gas. Since high destruction efficiencies generally require high temperatures and good mixing (high turbulence), these factors enabling good control of dioxins and furans promote the increased formation of nitrogen oxides (NO_x) and other acid rain precursors as well as the vaporization of heavy metals in the waste feed and the entrainment of particulate matter. Similarly, good combustion of municipal solid waste can minimize the formation and improve the destruction of organics in the waste feed, but will be ineffective in limiting acid gas formation and can enhance the vaporization of trace heavy metals.

The air pollutants resulting from the combustion of wastes may be classified into four categories: trace hazardous organics, trace heavy metals, acid gases, and particulate matter. An additional category or class could include pathogenic, cytotoxic, or other medical waste. However, this class will not be included here as it is assumed that radioactive materials will be excluded from medical wastes to be combusted and that combustion temperatures will be sufficiently high [800°C (1470°F) or more] to destroy pathogenic and cytotoxic materials. Thus, the selected control strategy for the four air pollutant categories must be capable of multiple pollutant control, and the optimum control system will depend on the required level of control of the targeted pollutants plus other site-specific factors. The residues, while much less in volume than the waste feed, will contain concentrated pollutants which may require treatment or removal prior to their environmentally safe disposition. Since the main focus of this paper is flue gas cleaning processes, the treatment, utilization, and disposal of residues will not be discussed.

REGULATORY STATUS

While the U.S. now has less stringent national air emission requirements for waste combustion than many industrialized European nations and Japan, EPA has announced its intention to propose revised technologically based new source performance standards (NSPS) for municipal waste combustors (MWCs) and operating guidelines for existing MWCs. It has also begun the regulatory development process for medical waste incinerators and is revising regulations for hazardous waste incinerators. Currently, state and local regulations or

permit requirements often specify the type of combustor and emission control needed for various wastes, so that the emission limits of operating units are usually tighter than the Federal standards. Table 1 presents selected emission standards for MWCs in the U.S., several U.S. states, and several foreign countries.[1] This listing is not intended to be complete as several of the governments shown control pollutant emissions in addition to those indicated.

The revised NSPS for MWCs in the U.S. are likely to require the control of pollutants other than particulate matter, the only presently controlled pollutant, and more stringent control of particulate matter. This was pointed out during the June 7, 1989, meeting of EPA's National Air Pollution Control Techniques Advisory Committee (NAPTAC) where spokesmen for EPA's Office of Air Quality Planning and Standards reported that regulatory alternatives under consideration for the revised NSPS included good combustion practices to limit dioxin and furan emissions, acid gas scrubbing (plus NO_x control), tighter particulate control which will also reduce trace metal emissions, and materials separation to exclude potential pollutants (such as lead and mercury) from the waste to be burned.

Technologies for controlling trace organic and heavy metal compounds, acid gases, and particulate matter to meet various national and local requirements have been applied in Europe and Japan. Many of these technologies are offered in the U.S. under licenses from European and Japanese vendors. They include both in-furnace and downstream controls, the former stressing the control of organics, NO_x, and acid gases and the latter also controlling heavy metals and particulate matter. Many of the emission control technologies to be discussed below have been applied to MWCs in Europe and Japan.

EMISSION CONTROL TECHNOLOGIES

In-Furnace Methods

In-furnace emission controls are designed to destroy combustible and toxic components, to preclude formation of these components, or to remove noxious components. Good combustion practices (GCPs) for MWCs were proposed in a 1987 EPA report to Congress[2] as a primary means to control dioxins and furans. The GCPs, currently being reviewed in the MWC regulatory effort, address in-furnace temperature control; combustion air supply and its distribution; CO, O_2, and load control; and other factors.

The injection of calcium compounds into the furnace of MWCs has been used to remove HCl and SO_2. Limestone ($CaCO_3$) injection at a mole ratio of $CaCO_3$ to HCl of 1.2 into the furnace [700 to 950°C (1300 to 1750°F) zones] with HCl concentrations of 500 to 800 ppm was reported (see Figure 1) to reduce HCl to 370 and 400 ppm, while a ratio of 4 lowered the uncontrolled HCl levels to 100 and 130 ppm, respectively. Figure 1 also shows the performance of in-duct injection of hydrated lime, but this will be discussed later under acid gas control.

Recently reported work in the U.S.,[3] where limestone ($CaCO_3$), lime (CaO), and hydrated lime [$Ca(OH)_2$] were added at the upstream end of a Westinghouse O'Connor combustor, found hydrated lime to be the most effective of these sorbents and no appreciable HCl or SO_2 removal with crushed limestone. With average baseline concentrations of 509 ppm for HCl and 145 ppm for SO_2 (volumetric concentrations referenced to 7% O_2 in dry gas), the HCl removal ranged from 25 to 76% and the SO_2 from 60 to 88% for a reagent (mole) ratio [Ca/(S + 0.5 Cl)] of 1.87 with hydrated lime addition. With lime addition at a reagent ratio of 2.8, the HCl removal ranged from 34 to 66% and the SO_2 removal from 20 to 73%.

The results of the limited data reported on in-furnace injection of calcium sorbents for controlling acid gas emissions indicate that this method alone is unlikely to attain the 90% HCl removal requirement or outlet HCl emission limit of 30 to 50 ppm as required in some U.S. states. It appears promising for removing 70% SO_2 when hydrated lime is used, but a more reactive sorbent is needed for high HCl control and possibly for SO_2 emission limits of 30 or 50 ppm in some states.

Methods to control NO_x in MWCs and their approximate control ranges in Japan are summarized in Table 2. Automatic combustion control, water spray into the furnace, flue gas recirculation, and ammonia injection are in-furnace NO_x controls, while ammonia injection with a catalyst and a wet scrubber with oxidation are post-combustion NO_x control processes.

The first three methods control oxygen and temperature to limit NO_x formation. Flue gas recirculation retards NO_x formation by reducing the oxygen for the initial stages of combustion, limiting the flame temperature, and enhancing the formation of NO_x reducing agents through the high moisture in the recirculated gas causing the water gas shift reaction and production of CO. Limited data show that flue gas recirculation reduced NO_x emissions by 10 to 20%, but with an apparent increase in CO emissions.[4]

The thermal reduction of NO_x, or selective non-catalytic reduction (SNCR), involves injecting ammonia or urea into the upper furnace to selectively reduce NO to N_2.[5] Since the ammonia/NO_x reactions are very temperature sensitive, the ammonia injection location(s) must be carefully selected to obtain the reducing reaction and to avoid ammonia slip. Figure 2 shows the furnace region where the thermal reduction of NO_x can be applied.

The thermal $DeNO_x$ method which uses ammonia injection into the furnace to reduce NO_x to NO has been applied to three MWCs in California. The Commerce plant has been operating for over 2 years and a NO_x reduction of about 50% with an ammonia slip of less than 2-3 ppmv has been achieved with the $DeNO_x$ system.[6] Short-term tests over one season of the year revealed average NO_x reduction of 69 and 63% for Units 1 and 2, respectively, at the Stanislaus County plant.[7] However, the plant owner/operator will not guarantee a NO_x removal rate of greater than 35-45% based on the limited performance data now

available. The thermal DeNO$_x$ system at the Southeast Resource Recovery Facility (Long Beach) is designed to supplement the flue gas recirculation system in controlling NO$_x$, but no data on its performance were given in Reference 4.

Recent testing in the largest municipal solid waste incineration plant in Switzerland evaluated urea and methanol in combination for controlling NO$_x$. With injection of these substances into flue gas between 815 and 1035°C (1500 and 1900°F), the NO$_x$ removal was between 65 and 80%.[8] The methanol was used to reduce ammonia slip and/or air preheater deposits, and was reported to reduce slip from 5 to 2.5 ppmv between 950 and 1000°C (1740 and 1830°F) when the NO$_x$ removal was 65%.

Information on reburning for NO$_x$ reduction is contained in Reference 9, while Reference 6 provides a good summary of NO$_x$ control methods for MWCs. Figure 2 also indicates furnace regions where reburning fuel may be supplied.

Particulate Matter Control

While the predominant method for particulate control on large waste combustors is the electrostatic precipitator (ESP), many new units are being equipped with fabric filters (baghouses) to complement acid gas scrubbers. A low emission [<45 mg/Nm^3 (<0.02 gr/dscf)] can be attained by an ESP with a high ratio of collector plate surface area to gas flow rate, such as 1700 m^2-min./Nm^3 (520 ft^2-min./ft^3). ESPs are also being used on MWCs required to meet an emission limit of 34 mg/Nm^3 (0.015 gr/dscf).

Fabric filters are rarely used without a spark arresting mechanism, upstream flue gas humidification or quenching, or sorbent injection to protect the fabric bags from hot gases and spark carryover. Both the pulse-jet-cleaned and reverse-air-cleaned baghouses are being operated on MWCs with particulate matter emissions below 45 mg/Nm^3 without operational upsets caused by varying waste feed and residue compositions that can negatively impact ESP performance.

Wet venturi scrubbers used on early MWCs (and still used on some older units) are not efficient enough to meet most current particulate matter control limits because of their lower removal efficiencies (80 to 95%). While water venturis can effectively remove fine particles, their application for this purpose entails high operating costs and reduced reliability caused by the high erosion and corrosion potential inherent in handling acidic flows.

Acid Gas Control

Dry, semi-dry, and wet processes are used to remove acid gases (HCl, HF, and SO_2) produced by waste combustion. The first two processes result in reaction products which are dry powdery solids and flue gas which is unsaturated with water on leaving the process. The sorbent used in dry processes is in a powder form, and humidification of the flue gas upstream of the dry

sorbent's injection may be used to enhance the acid gas/sorbent reaction (through reducing the approach to saturation temperature) when lime is used. In the spray dryer absorption (semi-dry) process, an alkaline sorbent slurry or solution is atomized into fine droplets and injected into the surrounding flue gas. The alkaline droplets react with the acid gases, and are dried on contacting the hot flue gas so that the reaction products are dry powders. In both the dry and semi-dry processes, all the dry solids may be entrained by the flue gas and carried to the particulate collector; however, most spray dryer absorbers are designed for removal of the heavier solids from their bottom section. Wet scrubbing processes use sorbent slurries or solutions which produce a clean water-saturated flue gas at a temperature lower than in the dry and semi-dry processes and require handling reaction products as wet solids or sludges.

The simplest process for removing acid gases is dry alkaline sorbent injection into flue gas from the furnace/boiler followed by particulate collection. When totally dry sorbents are used, they require substantial contact time with the targeted flue gas pollutant to achieve high removal. Thus, a fabric filter is preferred when high acid gas removal is needed because the filter cake permits better sorbent/flue gas contact than an ESP and also contains unreacted sorbent to counter sudden increases of acid gas concentrations in the flue gas. As noted earlier, a spark arrestor or flue gas quenching may be needed to ensure that spark carryover from the furnace/boiler does not damage the fabric bags. Figure 3 shows a simple dry sorbent injection control system with the option for injecting sorbent into the flue gas duct or into a circulating fluid-bed reactor having longer sorbent/flue gas contact time than duct injection alone.

Lime injection into the flue gas duct is frequently used in Japan in combination with an ESP. Except in heavy industrialized areas, the particulate standard (see Table 1) and HCl standard (430 ppmv at 12% O_2) are readily attained by this control combination. For example, an inlet HCl concentration ranging from 600 to 800 ppmv (corrected to 12% O_2 and dry gas) would require an HCl removal of 28 to 46% to meet the HCl standard, and higher control (lower HCl) might follow that shown in Figure 1 if hydrated lime is the sorbent. Some SO_2 removal would also be anticipated with sorbent injection, but SO_2 control is not generally needed as the uncontrolled SO_2 concentration for Japanese MWCs ranges from 60 to 100 ppmv and the standard approximates 100 ppmv, except in special areas.

Hydrated lime injection into flue gas upstream of fabric filters is used to control HCl and SO_2 emissions on several small MWC units in the U.S. Tests on the two 90 tonne/day (100 ton/day) MWC units in Claremont, NH, showed 95% HCl removal for both units and 85 and 75% SO_2 removal on Units 1 and 2, respectively, at stoichiometric ratios (SRs) of 3.0 and 3.2.[10] In these systems, the hydrated lime is blown countercurrently into the converging section of the venturi just upstream of the fabric filter. The three parallel MWCs, in Springfield, MA, each designed for 109 tonnes/day (120 tons/day), are equipped with individual flue gas cleaning (FGC) systems. The FGC system consists of a dry absorption reactor (see Figure 3) using hydrated lime [$Ca(OH)_2$] followed by a pulse-jet-cleaned baghouse. Control efficiencies of

94% for HCl and 83% for SO_2 were reported for inlet concentrations of 503 ppmv for HCl and 129 ppmv for SO_2, respectively (concentrations referenced to 12% CO_2 in dry gas).

Spray dryer absorption is more effective than dry injection since the approach to saturation temperature of the flue gas is lower, and acid gas removal increases with decreasing approach to saturation temperature. Waste heat recovery (air preheater) preceding the spray dryer absorber can improve energy recovery while achieving the desired approach to saturation temperature with reduced water use in the absorber. Figure 4 illustrates a spray dryer absorption system.

Tests on commercial MWCs have demonstrated HCl removals of 90% and SO_2 removals above 70% with lime spray absorbers followed by either fabric filters or ESPs.[10,11] Results of tests on three lime spray dryer absorber/fabric filter units at Bridgeport, CT, indicated 99% HCl removal and from 93 to 98% SO_2 removal at SRs of 2.4 to 3.0. Results for similarly sized units at Millbury, MA, but equipped with ESPs rather than fabric filters, were 97% HCl and 73% SO_2 removal at an SR = 2.2 for Unit 1 and 99% HCl and 79% SO_2 removal at an SR = 3.0 for Unit 2. Reference 11 provides results for EPA tests at four sites.

Wet scrubbers, preceded by an ESP with 99% or higher control, often use sodium hydroxide (NaOH) rather than calcium compounds because of its higher reactivity and despite its higher unit cost in cleaning flue gas from waste combustors. They are particularly preferred where the high control of trace heavy metal vapors (especially Hg) and condensible organics in addition to acid gases is needed since wet scrubbers operate with lower flue gas temperatures than in dry or semi-dry scrubbers. Figure 5 shows a wet scrubber that, in addition to removing acid gases and providing for effluent water treatment, uses a heat exchanger downstream of the scrubber to condense water vapor from saturated flue gas and to remove submicrometer-sized particles and additional metallic vapors. This cooling followed by heating of the gas limits the visible steam plume leaving the stack as well as reducing the opacity of the stack gas through removal of fine particles and aerosols. Removal of trace metals from the effluent is accomplished by additives which cause the metals to precipitate and permit their separation and removal. The remaining effluent may require adjustment of its pH prior to being discharged to a public water body or stream, if permitted.

A wet scrubbing system operated with zero effluent discharge is illustrated in Figure 6. The system has two acid gas venturi scrubbers in series, the first being a water prescrubber for HCl removal (with some additional particulate removal) and the second using NaOH for SO_2 removal. The effluents from both venturis (the first one after neutralization by lime addition) are pumped to the spray dryer, which functions primarily to evaporate liquid. The cooled flue gas from the spray dryer enters an ESP or fabric filter prior to entering the prescrubber. This system, now used in West Germany with an ESP, operates without effluent discharge.

Wet scrubbers (Figure 5) are used on waste combustion units in Japan and Western Europe, mainly to achieve high control of heavy metals and to facilitate their separation from other scrubber wastes and high concentration prior to disposal. Both systems (Figures 5 and 6) can achieve over 95% HCl removal, 90% or more SO_2 control, and high removal of condensible trace metals and organics (dioxins/furans). As shown by the figures, wet scrubbers are complex relative to dry and semi-dry scrubbers, the complexity increasing as the number of pollutants to be removed increases. They also have higher capital costs but may be less costly to operate if high pollutant removals and metals removal from scrubber residuals is required.

Table 3 compares the effectiveness of acid gas control systems and shows that effective acid gas control can be attained with dry, semi-dry, or wet flue gas cleaning systems. While HCl and HF control is relatively easy, SO_2 control is more difficult and is enhanced by wet and semi-dry systems operating at and near the saturation temperature of the flue gas. In the U.S., the lime spray dryer absorber/fabric filter has been predominantly used in recent MWC applications.

Post Combustion NO_x Control

NO_x control exceeding that normally expected with in-furnace controls is being required in areas of low ambient air quality and to prevent further deterioration or to improve air quality in heavily industrialized regions. NO is the predominant component of NO_x and, because of its low reactivity and water solubility, it is also probably the most costly and difficult flue gas component to remove. Wet scrubbing control of NO_x, now used in Europe and proposed in Japan, is based on oxidation-absorption. Selective catalytic reduction, originally developed in Japan for coal- and oil-fired plants, is also being applied to MWC plants in Europe and Japan.

Since NO_x contains 95% or more NO, the oxidation-absorption method for NO_x control adds an oxidizer, such as sodium chlorite ($NaClO_2$), to the scrubber (Figure 5) or prescrubber (Figure 6) to oxidize NO in the flue gas to NO_2. For example, adding $NaClO_2$ to the prescrubber (first venturi scrubber) of Figure 6 and raising the pH to 3 or 4 would result in the oxidation of NO to NO_2 and its subsequent absorption in this and the following SO_2 scrubber. This NO_x control method is used in several West German plants.[12]

Selective catalytic reduction (SCR) options for NO_x control are illustrated in Figure 7. In conventional SCR, acid gas and heavy metals removal must precede SCR for high NO_x reduction and avoidance of premature catalyst failure due to poisoning. If the thermal penalty of prescrubbing to remove acid gases and metals is acceptable, then 80 to 90% NO_x can be removed with a NH_3/NO mole ratio of 1.0 and NH_3 slip of 5 ppm. A system of this type (Figure 7c) is being installed in a West German MWC plant (Munich South) and will have a lime spray dryer absorber/fabric filter upstream of the SCR reactor.[13] Flue gas leaving the fabric filter at close to 125°C (255°F) will be heated prior to NH_3 injection into the gas and its entry into the SCR unit operating at about 320°C (610°F). The plant will have two units, each with a capacity

of about 1000 tonnes/day (1100 tons/day), and a NO_x emission limit of 35 ppmv which will require a removal efficiency exceeding 88%. Other emission limits require removals in excess of 99.9% for particulate matter, 99% for HCl, and 95% for SO_2.

The SCR system with low temperature catalyst, shown in Figure 7b, is being used at several MWC plants in Japan[14] and was selected for a planned unit in California that was cancelled. The SCR unit follows the fabric filter (as in the Munich South plant but without gas reheating) which is preceded by dry lime injection into the venturi for HCl control. The catalyst contacts flue gas at 190 to 280°C (374 to 536°F) compared with 300 to 400°C (572 to 752°F) for conventional SCR. Performance tests at a 130 tonne/day (144 ton/day) plant indicated 83% NO_x removal (design value of 80%) for an inlet NO_x concentration of 140 ppmv and a flue gas temperature of 200°C (392°F). Similar results for a 150 tonne/day (165 ton/day) unit were 57% NO_x control (design value of 50%), inlet NO_x at 98% ppmv, and SCR unit operation at 246°C (475°F). The mole ratio of NH_3 to NO_x was 1.05 at the first plant noted and 0.67 at the other unit. All NO_x concentrations given are referenced to 12% O_2.

With a system similar to that in Figure 8, Mitsubishi claims: 98% HCl, 85% SO_x, and 80% NO_x removal with less than 20 ppmv of each of these pollutants in the clean flue gas; and 99% particulate matter (dust) removal with less than 20 mg/Nm^3 (0.008 gr/dscf) in the outlet flue gas.[15]

Post Combustion Organic Pollutant Control

While the mechanisms of controlling dioxins, furans, and trace metals are not well understood, their capture by condensation or attachment to particles is believed to be significant. Dioxin and furan reactions with caustic reagents and removal of the products by highly efficient particulate control are also suspected. Limited field test data indicate that the lime spray dryer absorber/fabric filter system can remove 99% of the dioxins and furans.[11] Tests on a single lime spray dryer absorber/ESP system showed average dioxin and furan removals of 67% and 60%, respectively.[11]

The above test results are consistent with earlier pilot plant data. These limited data showed the lime spray dryer absorber/fabric filter system to be more effective in controlling dioxins and furans than the lime spray dryer absorber/ESP system. However, several MWC units now under construction in the U.S. are using larger ESPs (four or five fields) than the three-field unit referred to above. These new units may have improved capture of fine particulate and, consequently, high capture of dioxins and furans, since these compounds are belived to become preferentially attached to or condensed on very small particles.

Table 4 summarizes full-scale test results for dioxin and furan control. These tests were made in coordination with compliance testing at four sites.[11] Pilot plant data indicate that highly effective control (>98%) of the chlorinated dioxin and furan isomers and other organics (chlorophenols, polycyclic

aromatic hydrocarbons, and chlorobenzenes) can be achieved using flue gas humidification preceding lime injection into a fluid bed reactor (see Figure 3) or lime spray dryer absorber in combination with a fabric filter.[16,17]

Heavy Metals Control

The mechanism for removal of trace heavy metals from flue gas is believed to be similar to that of organic compounds, where effective control of particles and low flue gas temperature are major factors. Reactions of sorbents with metals, however, are not important factors in metals control.

The heavy metals present in flue gas as chlorides, sulfates, oxides, or other forms are cooled as they pass from the furnace to the flue gas cleaning system. Some condense and are adsorbed, mostly on the surface of flyash particles. If the gas temperature into the flue gas cleaning system is 200°C (392°F) or less, then only Hg vapor is of significant concern, as indicated by Figure 9.[18] As shown in this figure, the approximate Hg concentration in flue gas is 0.5 mg/m^3 for MWCs, but the concentration may be much higher with industrial waste.

Very high metals control has been achieved by dry, semi-dry, and wet scrubbers. Pilot plant studies with dry and semi-dry scrubbers for Environment Canada[6] indicated metal (arsenic, antimony, cadmium, lead, nickel, and zinc) removals above 99% when the fabric filter inlet temperature was 140°C (284°F) or less. Mercury removal at this temperature was 94% for the dry system and 95% for the semi-dry one. Reported metals control data generally are 95% or more for heavy metals with the exception of Hg (see Table 5). With vapor condensation believed to be important for Hg control, wet scrubbers, because of their operation at lower flue gas temperatures, would appear to be better suited for this purpose than dry or semi-dry ones. Wet scrubbers are widely used in Sweden and Switzerland, which have similar low Hg emission limits for MWCs. However, a lime spray dryer absorber/ESP equipped MWC in Zurich is also meeting the Swiss Hg standard, although a proprietary additive is added to the flue gas entering the absorber to enhance Hg capture.

SUMMARY

Dry, semi-dry, and wet scrubbers are being used on full-scale waste combustors to meet emission standards and permit conditions. The scrubbers are effective in controlling acid gases, trace organics, trace heavy metals, and particulate matter. The choice of scrubber type depends on the pollutants to be controlled and the control level required.

Dry sorbent (lime) injection is used extensively in Japan for HCl control, but wet scrubbing is preferred where high metals and other pollutant control is required. The ESP/wet scrubber combination appears to be favored in Western Europe although a large MWC plant (2000 tonnes/day) will use lime spray dryer absorber/fabric filter units and be followed by conventional SCR systems after flue gas reheating. In the U.S., dry scrubbers have been installed on small MWC units, while no wet scrubbers for acid gas control are currently being

operated on MWC units. Several operating MWC plants in the U.S., all in California, use thermal DeNO$_x$, while SCR is being incorporated in a large MWC plant in West Germany.

HCl removals exceeding 90% and SO_2 removals of 70% or more are being achieved by new MWC units in the U.S. with both dry and semi-dry scrubbers, although the latter are receiving wider acceptance. The semi-dry units with fabric filters have demonstrated organic and heavy metal (with the exception of Hg) controls of 99% or greater. Tests on a single full-size lime spray dryer absorber/ESP system on a MWC unit showed the dioxin and furan removals to be under 70%. No metals control data were reported for this unit.

Both ESPs and fabric filters are meeting current particulate control requirements and attaining removal efficiencies above 99%. Limited data indicate that fabric filters on operating units are more effective for multi-pollutant control than ESPs, their advantages appearing to be in better control of Hg, dioxin, and furan emissions.

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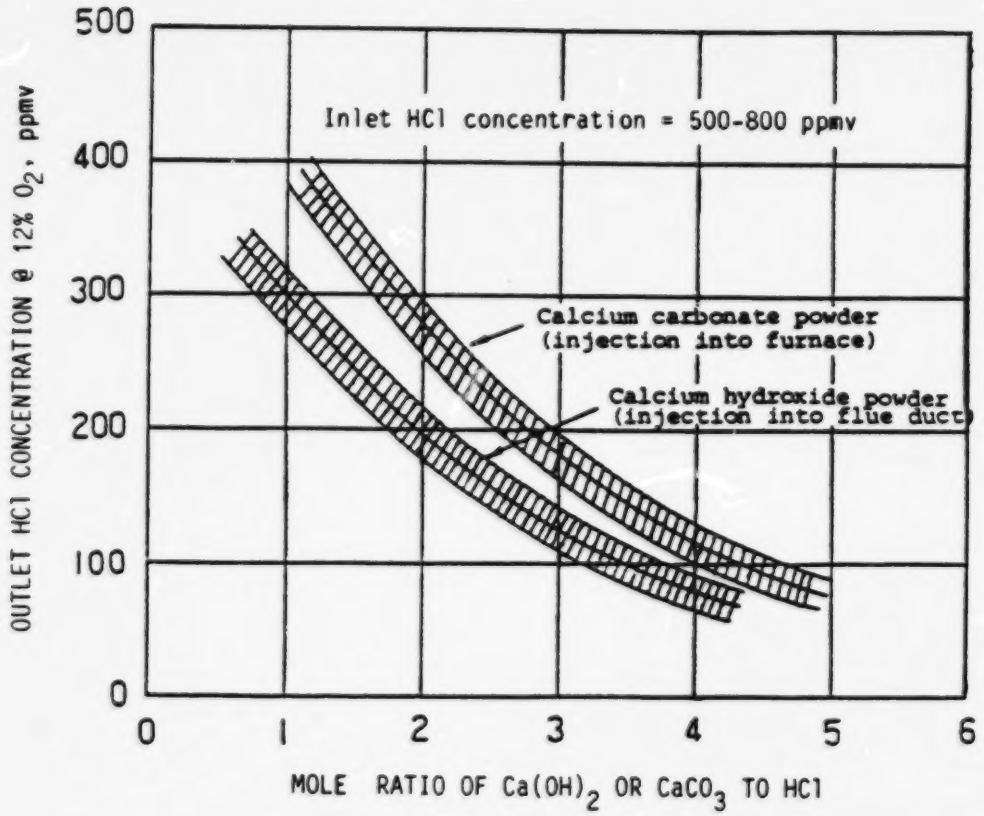


Figure 1. HCl removal by dry sorbent injection into furnace and flue gas duct. (Courtesy of Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan)

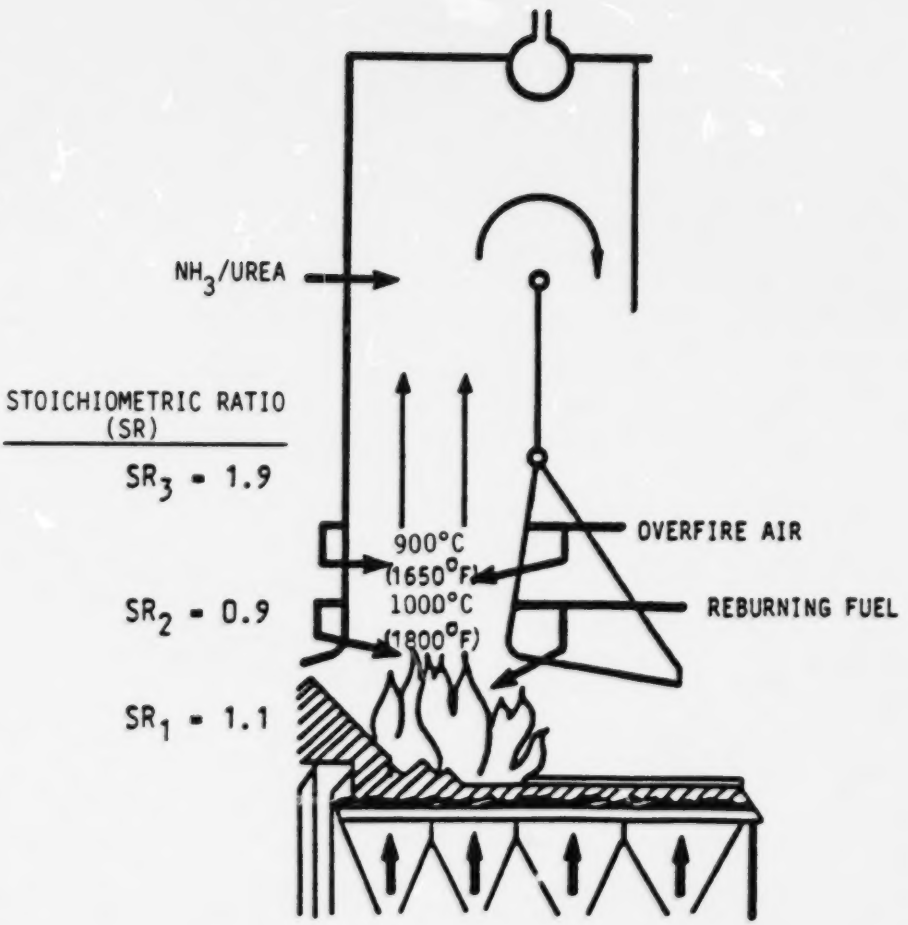


Figure 2. Reburning and thermal $DeNO_x$ in a municipal waste combustor.[1]

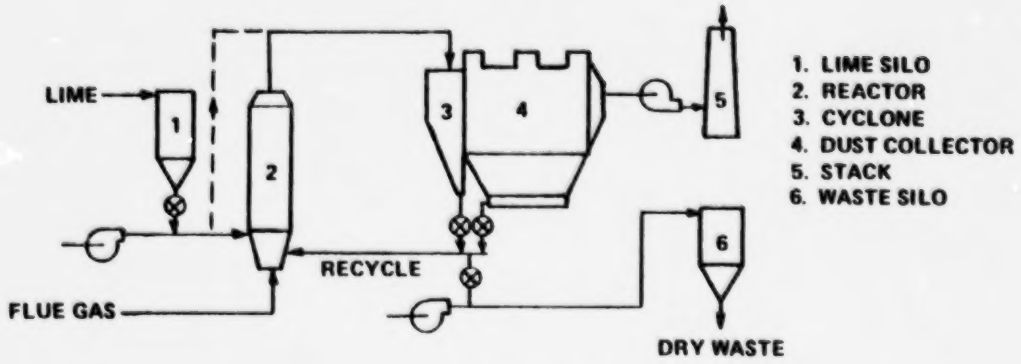


Figure 3. Dry sorbent injection into fluid bed reactor or flue gas duct (dashed line).[1]

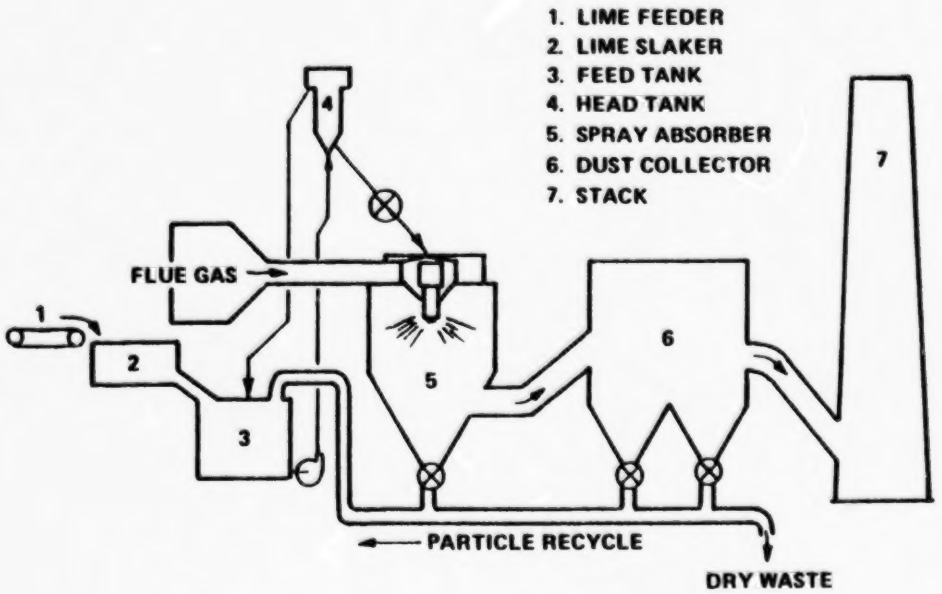


Figure 4. Spray dryer absorption (semi-dry) process.[1]

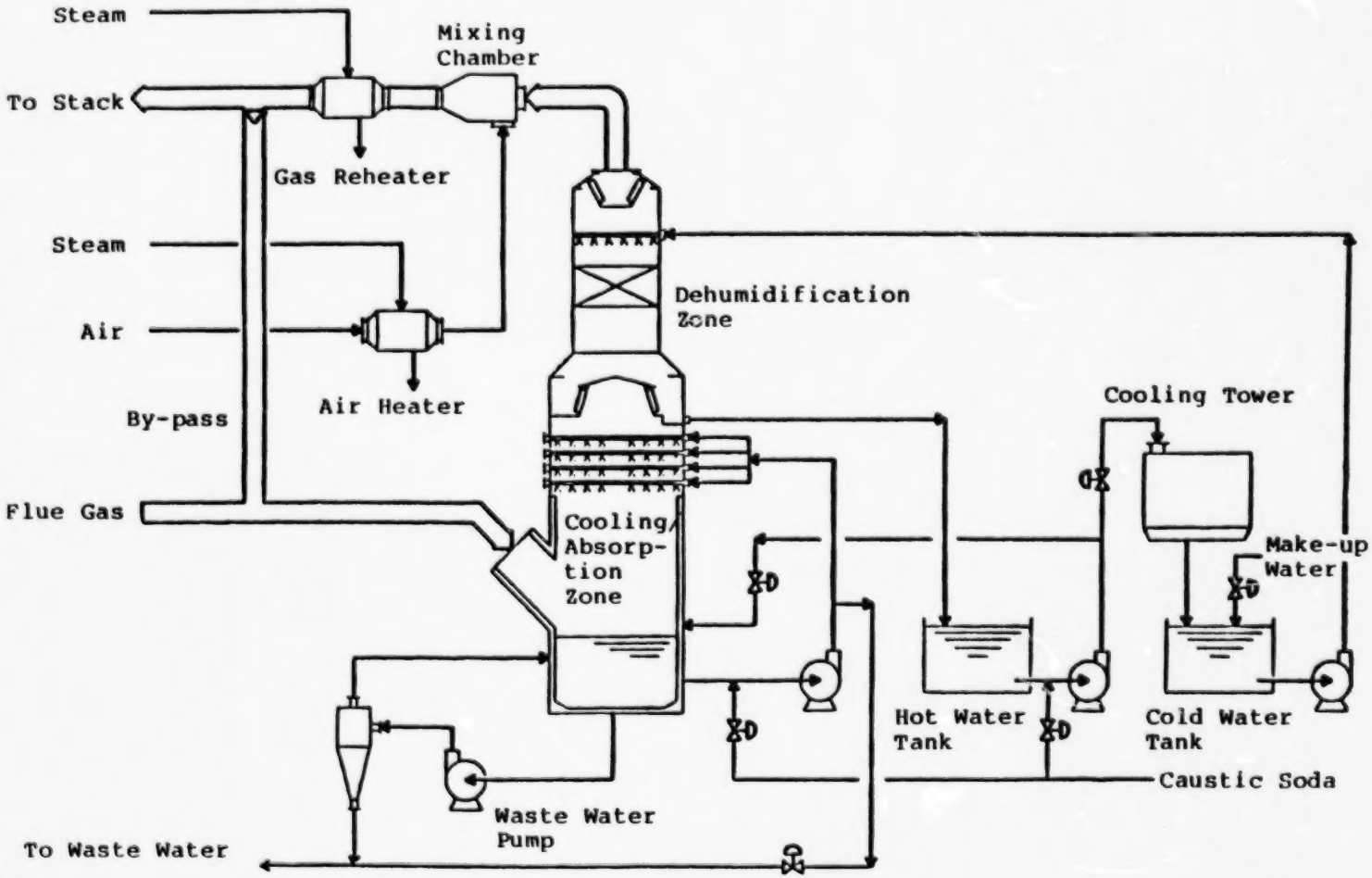
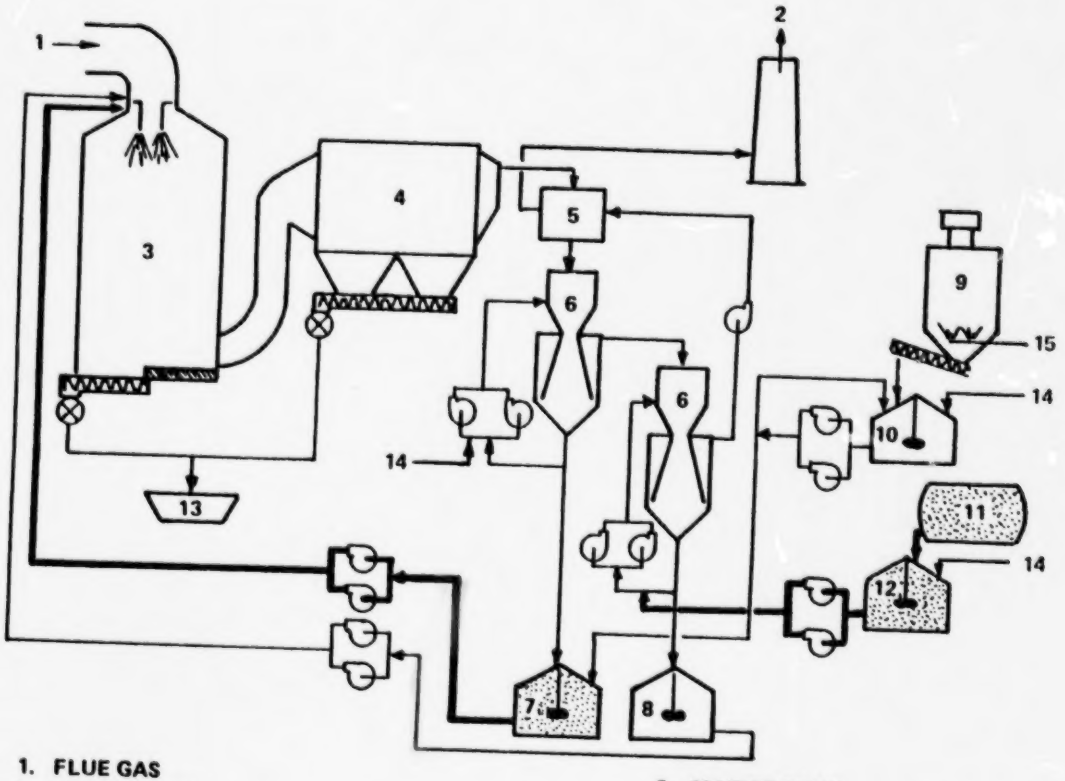


Figure 5. Wet scrubbing system. (Courtesy of Hitachi Zosen Corp., Osaka, Japan)



1. FLUE GAS
2. EXHAUST GAS
3. SPRAY DRYER
4. ELECTROSTATIC PRECIPITATOR OR FABRIC FILTER
5. GAS-GAS HEAT EXCHANGER
6. VENTURI SCRUBBER
7. NEUTRALIZATION TANK
8. SLUDGE TANK
9. LIME SILO
10. LIME SLAKER
11. SODIUM HYDROXIDE STORAGE
12. SODIUM HYDROXIDE FEED TANK
13. DRY WASTE
14. WATER
15. DRY AIR

Figure 6. Wet scrubbers with zero effluent discharge.[1]

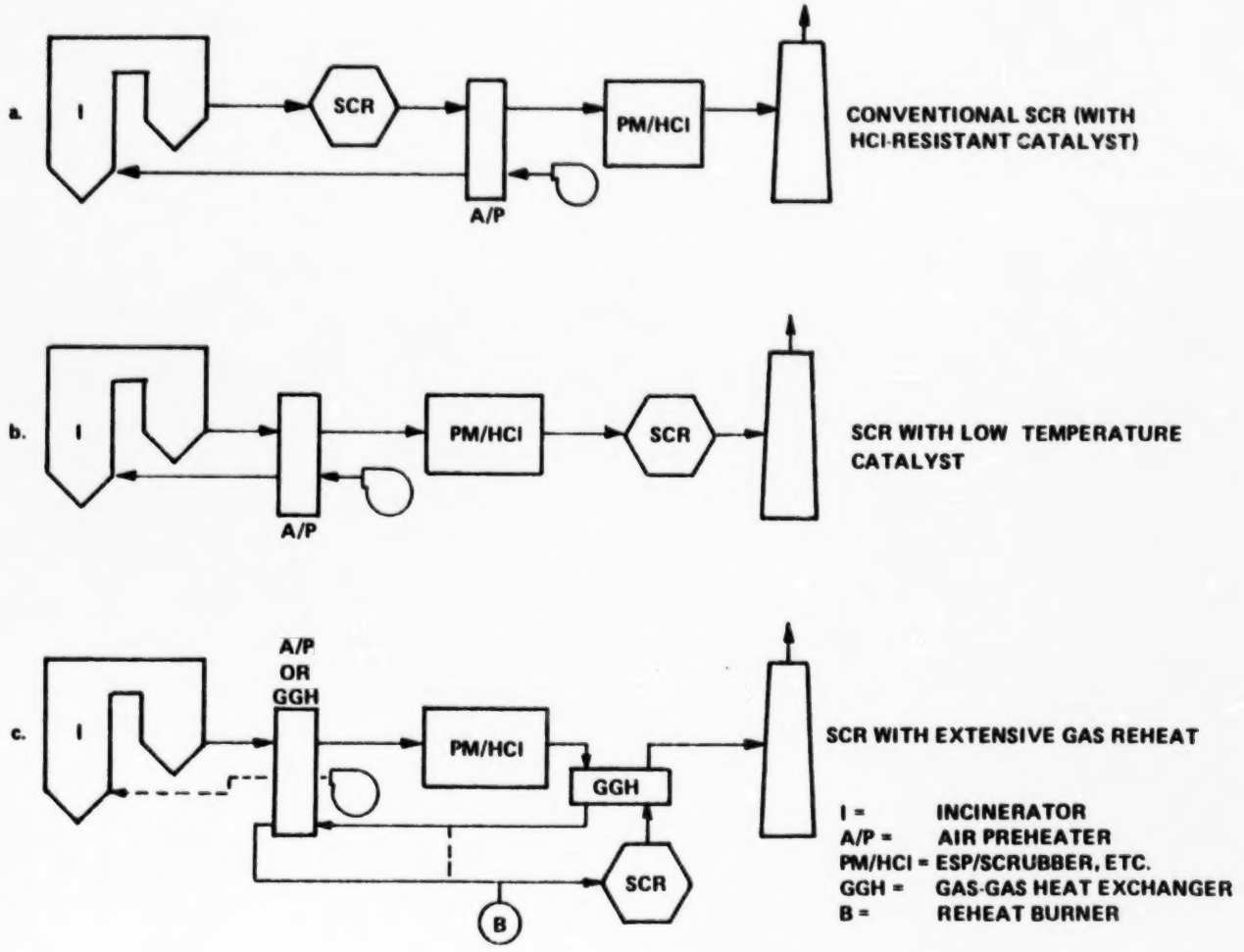


Figure 7. SCR options for incinerators.[1]

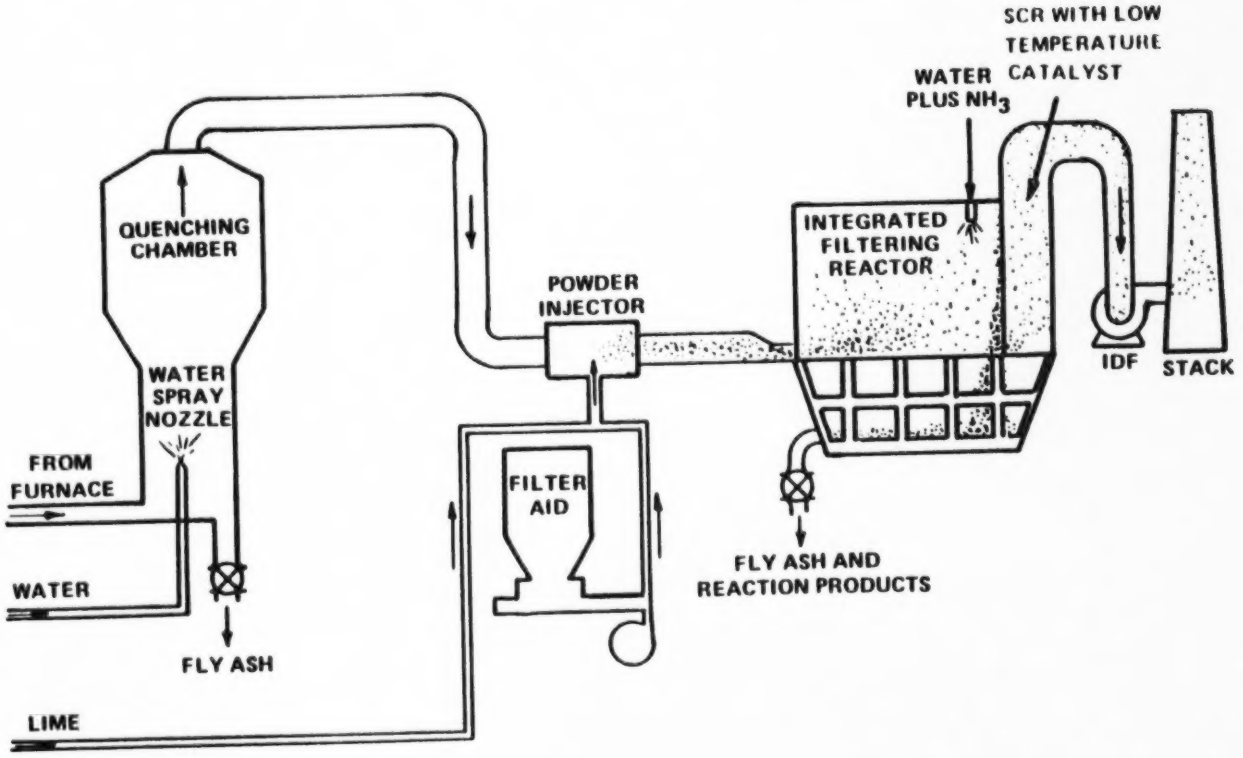


Figure 8. Integrated flue gas cleaning system for waste-to-energy plant.[1]

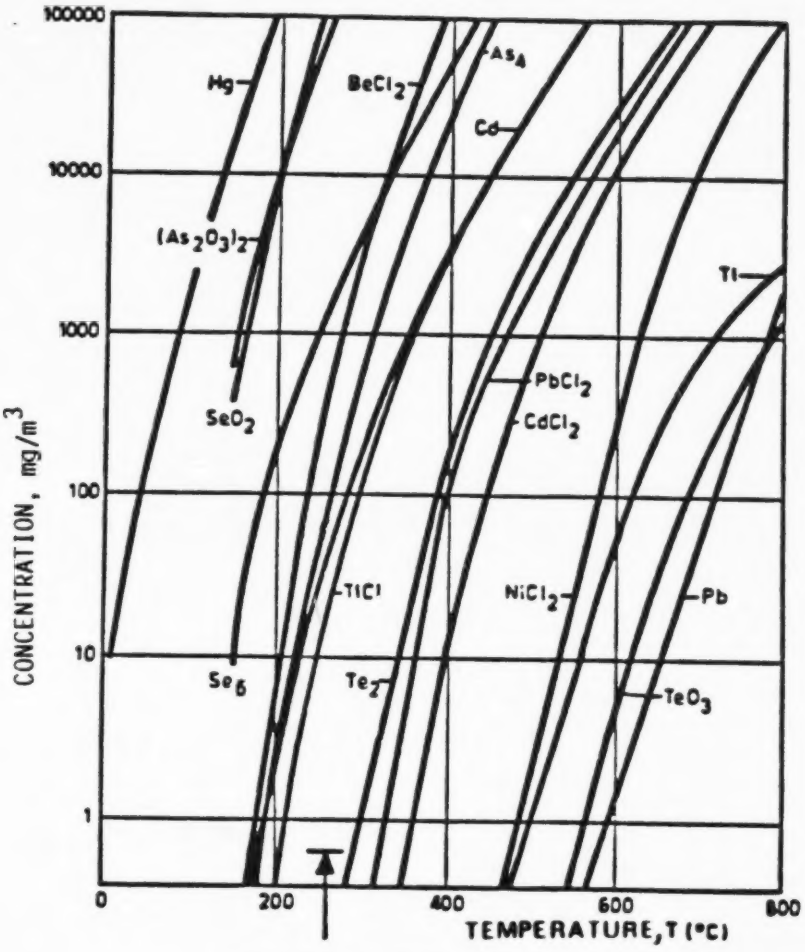


Figure 9. Saturation curves for selected metals and metal compounds.[18]

TABLE 1. SELECTED EMISSIONS STANDARDS FOR MUNICIPAL WASTE INCINERATORS[1]

	U.S.[a]	California	Connecticut	Michigan	Japan	Sweden[b]	West Germany
Solid Particulate Matter gr/dscf (mg/m^3)	0.046 (113)	0.01[c] (25)	0.015 (37)	0.015 (37)	0.061[d] (150)	0.008 (20)	0.012 (30)
Carbon Monoxide, ppm	------	----------	---------	113(24-hr avg)	----------	------	80
Hydrogen Chloride	------	30 ppmv (scrubbers required)	90% reduction	90% reduction	430 ppmv (700 mg/m^3)	63 ppmv (100 ng/Nm^3)	31 ppmv (50 mg/Nm^3)
Sulfur Dioxide, ppm	------	30	135 (0.32 lb/10^6 BTU)	86	varies[e]	New SO_2 limits reduce all acids	35 (200 mg/Nm^3)
Dioxins Measured as 2,3,7,8 - tetra-chlorodibenzo-p-dioxins (TCDD)	------	---------[f]	----------[g]	----------	----------	Existing plants: 0.5-2.0 ng/Nm^3 New plants: 0.1 ng/Nm^3	----------
Total Organics, mg/m^3	------	----------	----------	----------	----------	--------	20
Mercury+Cadmium+Thallium mg/m^3 (includes vapors)	------	----------	----------	----------	----------	0.08 (Hg only)	0.2
Gas Correction	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	12% O_2 dry	10% CO_2 dry	11% O_2 dry

[a]Revised NSPS for pollutants scheduled to be proposed in 1989.
[b]Swedish Environmental Protection Board's "Temporary Emission Goals," July 1986.
[c]California regulations permit more stringent local limits. Two state guidelines are reported: 0.01 gr/dscf (25 mg/m^3) for total solid particulates (TSP) and 0.008 gr/dscf (20 mg/m^3) for particles less than 2 μm.
[d]Based on continuous gas flows >25,280 scfm (40,000 m^3/h). For flows ≤25,280 scfm, the particulate matter standard is 0.20 gr/dscf (500 mg/m^3). For new plants in special areas, this standard is 0.033 gr/dscf (80 mg/m^3) for plants having >25,280 scfm and 0.061 gr/dscf for those having ≤25,280 scfm.
[e]Based on formula related to stack height and plant location. Typically, plant sulfur dioxide emissions range from 60 to 100 ppm so that control is not required except for new plants in special areas.
[f]Pollutant control requires use of the Best Available Control Technology (BACT), but no technology is specified.
[g]The use of dry gas scrubbers and baghouses is expected to improve removal over ESPs alone.

TABLE 2. NO_x CONTROL OPTIONS FOR MSW PLANTS

(Courtesy of Hitachi Zosen Corp., Osaka, Japan)

Systems	Attainable Control Level (ppm v/v, dry, 12%O_2) 150 120 100 90 80 70 60 50 40	Remarks
Uncontrolled	◄——————►	
Automatic Combustion Control	◄——————►	
Water Spray in Combustion Chamber	◄——————►	used with automatic combustion control
Flue Gas Recirculation	◄——————►	ditto
Ammonia Injection without Catalyst	◄——————►	ditto
Ammonia Injection with Catalyst	◄——————►	
Wet Scrubber with Oxidization	◄——————►	

Note: NO_x concentration is corrected by O_2 percentage in Japan, not by CO_2 percentage.

TABLE 3. EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL[a])[4,10,11]

Control System	Pollutant		
	HCl	HF	SO_2
Dry Injection + Fabric Filter	>90	92	>75
Spray Dryer Absorber + ESP	>95	-	>70
Spray Dryer Absorber + Fabric Filter	44-99	86[b]	70-98

[a]All values referenced to dry gas with 12% CO_2.
[b]Design value.

TABLE 4. CONTROL OF DIOXINS AND FURANS[11]

	Reduction Average Values After Correction to 12% CO_2[a]	
	Lime Spray Dryer Absorber/ Fabric Filter[b] (%)	Lime Spray Dryer Absorber/ Electrostatic Precipitator[c] (%)
Chlorinated Dibenzo-p-dioxin (CDD)	>96	>66
Chlorinated Dibenzofurans (CDF)	>99	>60
CDD + CDF	>98	>62

[a]Values of CDD and CDF do not include non-detectable congeners (i.e., those below minimum detection limits).
[b]Removals are based on short-term tests on three MWCs.
[c]Removals are based on one short-term MWC test.

TABLE 5. CONTROL OF HEAVY METALS WITH LIME SPRAY DRYER ABSORBER/FABRIC FILTER SYSTEMS[11]

Metal	Removal(%)
Arsenic	>99
Cadmium	>99
Chromium	>99
Lead	>99
Mercury	94-99